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Plasma Source Ion Implantation is a process for improving the surface hardness and wear characteristics of components for automobiles, aircraft, machine tools, and prosthetic devices. This view inside the process chamber shows aluminum automotive pistons being treated to improve their wear properties.

Plasma Source Ion Implantation for Enhancing Materials Surfaces

Los Alamos National Laboratory, Empire Hard Chrome, General Motors, North Star Research, and University of Wisconsin

With our Plasma Source Ion Implantation (PSII) process, nitrogen or carbon ions are implanted into metallic surfaces to improve the surface hardness and wear characteristics of parts for automobiles, aircraft, machine tools, and prostheses, without requiring elevated temperatures or employing carcinogenic or hazardous chemicals. PSII provides the ability to enhance the surfaces of either large, complex parts weighing many tons or large numbers of individual components, leading to decreased treatment times and dramatic reductions in processing costs.

The Invention—Characteristics and Advantages

In the PSII process, a gas containing carbon or nitrogen is introduced at very low pressure into a metallic vacuum chamber where radio-frequency waves strip electrons from the gas atoms to create positively charged ions and free electrons. Metallic targets such as auto parts are immersed in the pool of ionized gas. Short pulses of negative voltage are then applied to the parts; as a result, the positively charged ions are accelerated and bury themselves in the parts' surfaces. Thus, PSII is not a coating process but a way of transforming near-surface layers of target parts into an integrated, protective layer. PSII could extend the lifetimes of some parts as much as 10 to 50 times.

Automobile, aircraft, and machine tool manufacturers have long sought ways to enhance the surfaces of parts to improve wear lifetimes. Electroplating has been widely used, but it produces hazardous effluents. Plasma nitriding and chemical vapor deposition are industrially accepted but operate at elevated temperatures (often greater than 600 degrees Celsius), excluding these processes from use on chrome-plated or lightweight alloy components because they deform, melt, or lose beneficial properties under high temperatures. Ion beam implantation is a newer technology, but as an expensive, line-of-sight process, its use has been limited to prosthetic joints, high-strength ball bearings, components for high-performance vehicles, and similar high-value-added applications. Unlike PSII, ion beam implantation is not easily applicable to treating large components or component arrays.

PSII is a cost-effective and practical alternative to conventional surface-hardening processes. Its processing is done at one-tenth the cost of conventional ion beam implantation and without the chemical wastes of electroplating. Because it operates at low temperatures (less than 100 degrees Celsius), PSII can reliably treat chrome-plated, precision-machined, or lightweight alloy (e.g., aluminum or magnesium) parts. In addition, as a large-scale, competitively priced treatment, PSII can provide harder, longer-lasting parts for autos, aircraft, and machine tools.

Los Alamos has the world's largest PSII demonstration facility, consisting of a 1.5-meter-diameter by 4.6-meter-long process chamber, with implantation capability in excess of 55 amps at up to 100 kilovolts and higher currents at lower voltages. An operating system provides automatic control of the PSII facility. The facility allows surface treatment of large numbers of manufactured parts at currents more than 100 times greater than those available by conventional ion beam treatment methods, making the process many times faster.

In 1995, Los Alamos began working with North Star Research and Empire Hard Chrome to develop

the first commercial PSII system. Based in part on suggestions from Los Alamos PSII team members, North Star Research developed and supplied to Empire Hard Chrome a PSII system with a process chamber of approximately 1 cubic meter. Empire Hard Chrome is now offering implantation of nitrogen into chrome-plated surfaces as a commercial service. To further ensure the widespread commercialization of PSII, a consortium consisting of Los Alamos, the University of Wisconsin, General Motors, Empire Hard Chrome, and ten additional private-sector members is further developing and commercializing the PSII technology for industrial use.

Applications

At the Los Alamos facility, we have demonstrated two primary applications: (1) nitrogen implantation into chromium and steel alloy surfaces and (2) carbon implantation and diamond-like-carbon deposition on various alloys. Component lifetimes have been increased more than tenfold for these applications. Although PSII has a wide range of manufacturing applications, industries that have already demonstrated benefits from our PSII process include the automotive industry (e.g., pistons, stamping dies) and the tool manufacturing industry (e.g., dies, cutting tools). The PSII system in operation at Empire Hard Chrome is currently being used to treat (with nitrogen) a range of chromium-plated parts. By extending the life of these parts up to five times, PSII reduces their manufacturing costs as well as minimizes the waste generated by chromium-plating processes.

Another application of PSII is to modify surface release characteristics of injection molds, thereby increasing their service lifetime. Preliminary tests with industrial partners have shown significant improvements, in some cases, in the lifetimes of molds treated with PSII. Application of adherent diamond-like-carbon layers to substrates that are subject to corrosion (such as non-stainless steels) has also been shown to be a promising application, potentially providing both wear-lifetime improvements and corrosion protection.

The widespread acceptance and application of our technology would yield an enormous benefit to the U.S. economy by creating a new market area: the PSII industry. The diffusion of our PSII technology will have far-reaching impact on many manufacturing industries, such as the automotive, machine tool, aerospace, and prosthetic industries, all of which currently use conventional coating techniques.

The process will greatly benefit the automotive industry. The demonstration by General Motors and Los Alamos using PSII to treat aluminum components is estimated to save $100 million per year for the auto maker. Increased use of aluminum and magnesium alloy auto parts will lead to the next generation of lightweight, fuel-efficient cars. Similarly, in manufacturing applications, PSII has been shown to increase the life of chrome-plated parts by more than 50 times, to increase the lifetime of tool steel by up to 10 times, and to reduce the friction coefficient of nitrogen-implanted tools up to 5 times. Increasing the life of chromium-plated dies, in turn, decreases the toxic waste generated by chromium-plating processes. Estimates indicate that a 10% improvement in tool industry products would increase the global market share of the U.S. by 10%, or $440 million.

The Los Alamos team participating in development and commercialization of PSII consisted of staff members from the Plasma Physics Group, the Ceramic Science and Technology Group, and the Plasma Physics Applications Group. Left to right: Carter P. Munson, Michael A. Nastasi, Donald J. Rej, Jay T. Scheuer, Blake P. Wood, Kevin C. Walter, Ricky J. Faehl, Ivars Henins. Not pictured: William A. Reass, Darrell A. Roybal, Jose A. Garcia.

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